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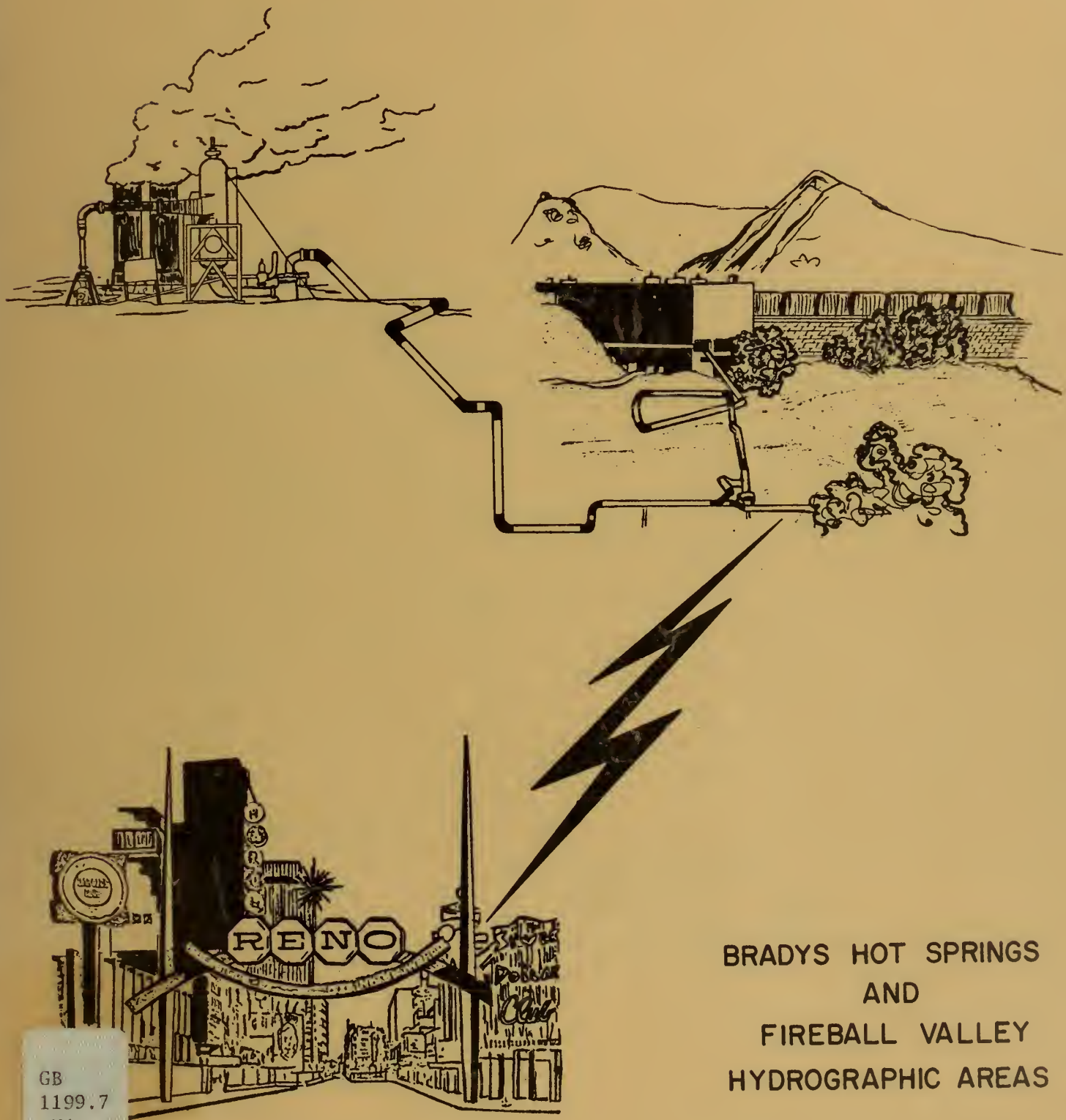
TECHNICAL REPORT

ON

GEOTHERMAL ENERGY DEVELOPMENT



BRADYS HOT SPRINGS AND FIREBALL VALLEY HYDROGRAPHIC AREAS

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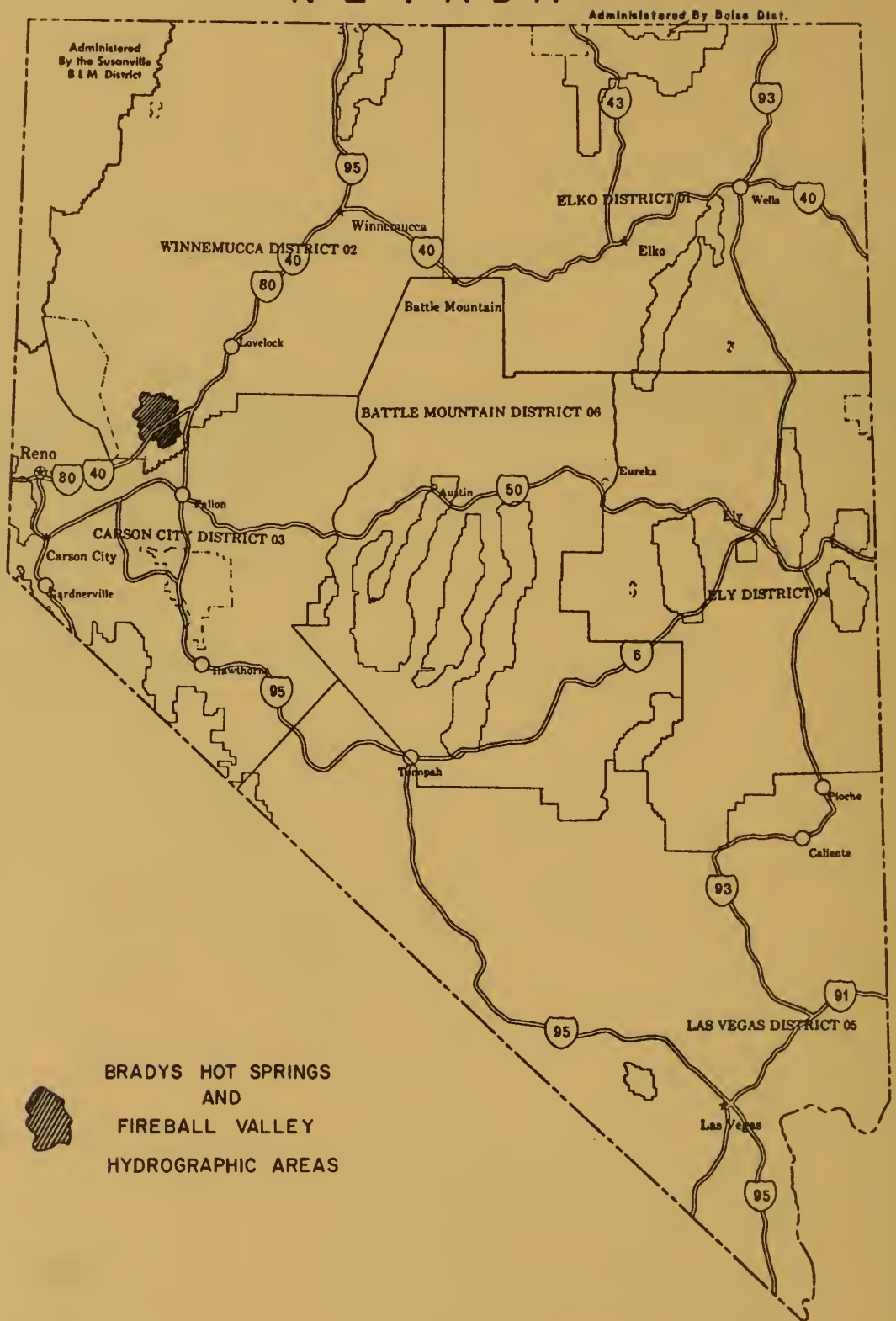

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TECHNICAL REPORT
on
Geothermal Energy Development
Brady's Hot Springs & Fireball Valley
Hydrographic Areas

by
Robert T. Webb

Introduction

The data in this technical report is supplementary to data included in the Environmental Analysis Record. Both the technical and the environmental data must be considered together to reach a judgement as to the conduct of a leasing program. The technical information presented here (with the exception of the Brady's Hot Springs geology) is equally applicable throughout all of Nevada. The final Environmental Statement for the Geothermal Leasing Program, covering all Federal lands, was published in October 1973, Additional data is contained therein.

Proposed Action

The proposal is to lease Federally owned potential geothermal resources in the Brady's Hot Springs and Fireball Valley hydrographic areas.

The geothermal energy leasing program would be conducted under the Geothermal Steam Act of 1970 and the regulations in 43 CFR 3200 and 30 CFR 270 which became effective January 1, 1974.

The proposal involves:

(A) The approval of "Notices of Intent to Conduct Geothermal Resource Explorations" on areas not connected with a lease (Form 3200-9).

(B) The issuance of Noncompetitive Geothermal Resource Leases (Form 3200-21).

(C) The issuance of Geothermal Resource Leases (Form 3200-21) on Known Geothermal Resource Areas by competitive bidding.

Geothermal Resource Leases, both noncompetitive and competitive, are between 640 and 2560 acres each. Such leases are issued for an initial term of 10 years and the term is extended if commercial production is reached.

The area under consideration involves two hydrographic areas (Brady's Hot Springs and Fireball Valley) encompassing approximately 128,600 acres. About one-half of the land involved is national resource land, while the other half (basically an alternate section checkerboard) is privately owned with no Federally owned minerals.

Geothermal Resources

The earth is a tremendous reservoir of thermal (heat) energy. Heat flows beneath the surface and dissipates. This is usually not noticeable because it is dissipated in small quantities.

The increase of heat with depth is called geothermal gradient. Normally it would average about $1^{o}F.$ for every 100 feet of depth. Some areas are discharging heat at rates of 10 to 1,000 times normal. These are the areas of interest for development of geothermal energy.

The heat source that creates these near-surface "hot spots" is either:

(1) A deep-seated magma (molten rock) from which the heat escapes via faults, or

(2) A shallow magma or magma cooling chamber in areas of fairly recent volcanic activity (within the last few million years).

Groundwater is heated by these energy sources and rises toward the surface. In some places the hot water is trapped by overlying impermeable rocks. In others it reaches the surface through faults. Hot springs, fumaroles, mud pots and geysers are the surface expressions of such escape.

Geothermal Systems

Two types of geothermal systems are considered to have present commercial application:

(1) Vapor-dominated systems (dry steam) are believed to contain both saturated steam and water in the reservoir. When a well is drilled, the decrease in pressure superheats and dries the steam. The steam may be used to drive a turbine directly. Vapor-dominated systems are believed to be relatively rare. Power production from such fields occurs at the Geysers in California, Lardarello, Italy; and Matsukawa, Japan. The Valles Caldera field in New Mexico appears to be of this type and is currently under development.

(2) Hot water systems are believed to result from a thermally driven convection system which moves the heated water upward. The upwelling hot water often penetrates the surface as hot springs, geysers, etc. When a well is drilled, a portion of the water flashes into steam and both water and steam come to the surface. The steam is separated from the water and used to drive a turbine. Power production from hot water fields is currently underway at Wairakei, New Zealand, Otaka, Japan; Cerro Prieto, Mexico and Pathe, Mexico.

U. S. Geothermal Development

The Geysers, in northern California, is the only commercially developed geothermal energy field in the United States, with the exception of local use for space heating in a number of places.

At the Geysers, five power generating plants operate on a vapor dominated geothermal system to produce 400 megawatts of electrical power. This is roughly equivalent of 2/3 the electrical power demand of the City of San Francisco. The ultimate capacity of the field, when fully developed, is estimated to be between 1,000 and 3,000 megawatts--sufficient power to satisfy the demands of the entire San Francisco Bay urban area.

The initial development at the Geysers was pioneered by Magma Power Company. Union Oil Company is the current operator.

Exploration has been going on for the last 15 years or so in many localities in the western States. Technical development problems and the economics of alternate fuel sources have thus far delayed commercial power development.

Nevada Geothermal Development

Between 200 and 300 hot springs are scattered over the State--evidence of higher than normal heat flows in many areas. During the 1800's and early 1900's resorts grew up around and used many of the hot springs.

Shallow wells, drilled into hot water systems, are currently used to heat homes (with simple heat exchangers) in the Stillwater and Steamboat-Moana areas. At Steamboat Springs, such hot water is used as a safe way to melt explosives.

Only in the last 15 years have serious attempts been made to develop Nevada's geothermal energy as a source of electrical power. From 1959 through 1965 there were approximately 50 exploration wells for this purpose. Magma Power Company and its affiliates drilled the majority of the wells, but U. S. Steel Corporation, Sun Oil Company, and Natomis were also active.

Exploration wells were drilled at Steamboat Hot Springs, the Needles area of Pyramid Lake, Fly Ranch, Monte Neva Hot Springs, Beowawe, Hot Springs Pt. (Crescent Valley), Wabuska, Fernley (Hazen), Hind's Hot Springs, Darrough Hot Springs, Brady's Hot Springs, Stillwater, and Wally's Hot Springs.

Most of this drilling was preceded by little detailed exploration, was conducted right on existing springs, and consisted of relatively shallow wells (±2,000 feet). The deepest well, at the Needles, reached 5,888 feet.

Drilling activity ceased in 1965, but at present a new flurry of activity is underway. Numerous companies, the Geological Survey, and the Atomic Energy Commission are conducting detailed exploration activities.

Chevron Oil Company and American Thermal Resources are now drilling an exploration well that may go to 10,000 feet at Beowawe. Phillips Petroleum Company has just completed a well a few miles southeast of Brady's Hot Springs, and Union Oil Company is currently drilling a well at Brady's.

Brady's Hot Springs - Fireball Valley Geology and Mineral Development

(A) Geology - The Brady's Hot Springs and Fireball Valley hydrographic areas consist topographically of broad basins and playas surrounded by broken hills.

The oldest rocks in the area are Jurassic dioritic rocks and Jurassic-Triassic (?) metamorphic rocks (phyllites, slates and schists) which are best exposed along the ridge between North Valley and Hot Springs Flat. These rocks form a basement on which the younger units have been unconformably deposited.

Tertiary volcanic and interbedded sedimentary rocks form most of the hills in the area. These units are of Miocene-Pliocene age and contain basalt, andesite and dacite lava flows; tuff and pumaceous pyroclastics; and interbedded shale, sandstone and diatomite sediments. They comprise the Chloropagus, Desert Peak and Truckee formations which total about 6000-7000 feet in thickness. These rocks reflect a time when the area was the scene of intense volcanic activity, dotted with volcanoes and small lakes.

The valleys and slopes contain sediments in the form of alluvial gravels, dissected alluvial fans, and some pediment gravels. Youngest of these Quaternary sediments are the Pleistocene Lake Lahontan fluvial deposits, playas and young fan gravels.

Folds and north-northeast striking high angle normal faults characterize the major structural deformation since Tertiary time. Thermal waters have deposited siliceous sinter in Lake Lahontan beds for about two and one-half miles along a north-northeast trending fault extending through the Brady's Hot Springs area. The most recent movement along the fault has raised the sinter deposits on the east side of the fault about six feet in Section 12, T. 22 N., R. 26 E. Rocks exposed east of the fault are sandstone, mudstone, and limestone deposited in an older lake that occupied the area in Pliocene time. The geology indicates a history of geothermal phenomena in the Brady's Hot Springs area over the past several million years.

(B) Mineral Occurrences - The Leete salt deposits, about four miles south-southwest of Brady's Hot Springs, were developed by the Eagle Salt Works in 1871 to provide salt to the mills in Virginia City. Maximum production was achieved from 1879 to 1884 during which 334,400 tons were produced. Subsequent production was on a decreasing scale until 1913 when the operation ceased. A borax operation in the vicinity was attempted in 1871 but failed.

The salt for the Eagle Salt Works was obtained by solar evaporation of a brine which comes nearly to the surface of the playa. Evidence of the old evaporation works remains.

A number of small gold and silver prospects are scattered along outcrops of the Jurassic metamorphic rocks along faults and near the contacts with intrusives. No production has been recorded.

Nearly pure diatomite beds occur in the middle member of the Truckee formation. Diatomite has been mined for a number of years from deposits in Section 20, T. 24 N., R. 26 E. The current owner is United Sierra Division, Cyprus Mines Corporation, who trucks the diatomite to the company plant in Fernley. Extensive diatomite exploration has taken place three to five miles northeast of Brady's Hot Springs and there is currently production by Cyprus Mines Corporation from a pit about one-half mile east of Interstate 80.

Highly vesicular and scoriaceous basalt is sporatically mined for use as decorative stone in landscaping and as facing rock from private lands about five miles south of Brady's Hot Springs.

(C) Geothermal Energy Development

Development drilling was sporadically carried out at Brady's Hot Springs between 1959 and 1965.

Magma Power Company, Geothermal Resources International and Earth Energy Inc. Division of Union Oil Company drilled seven shallow cable tool wells, deepened two of them, and drilled one deep rotary well during that time period.

Test results show that Brady's Hot Springs has two major thermal horizones or zones capable of yielding major volumes of super-heated geothermal fluids under controlled conditions. The upper zone lies between 220 and 360 feet below the ground surface with temperatures around 310°F. The lower zone is 3,000 to 5,050 feet deep with bottom hole temperature of 414°F.

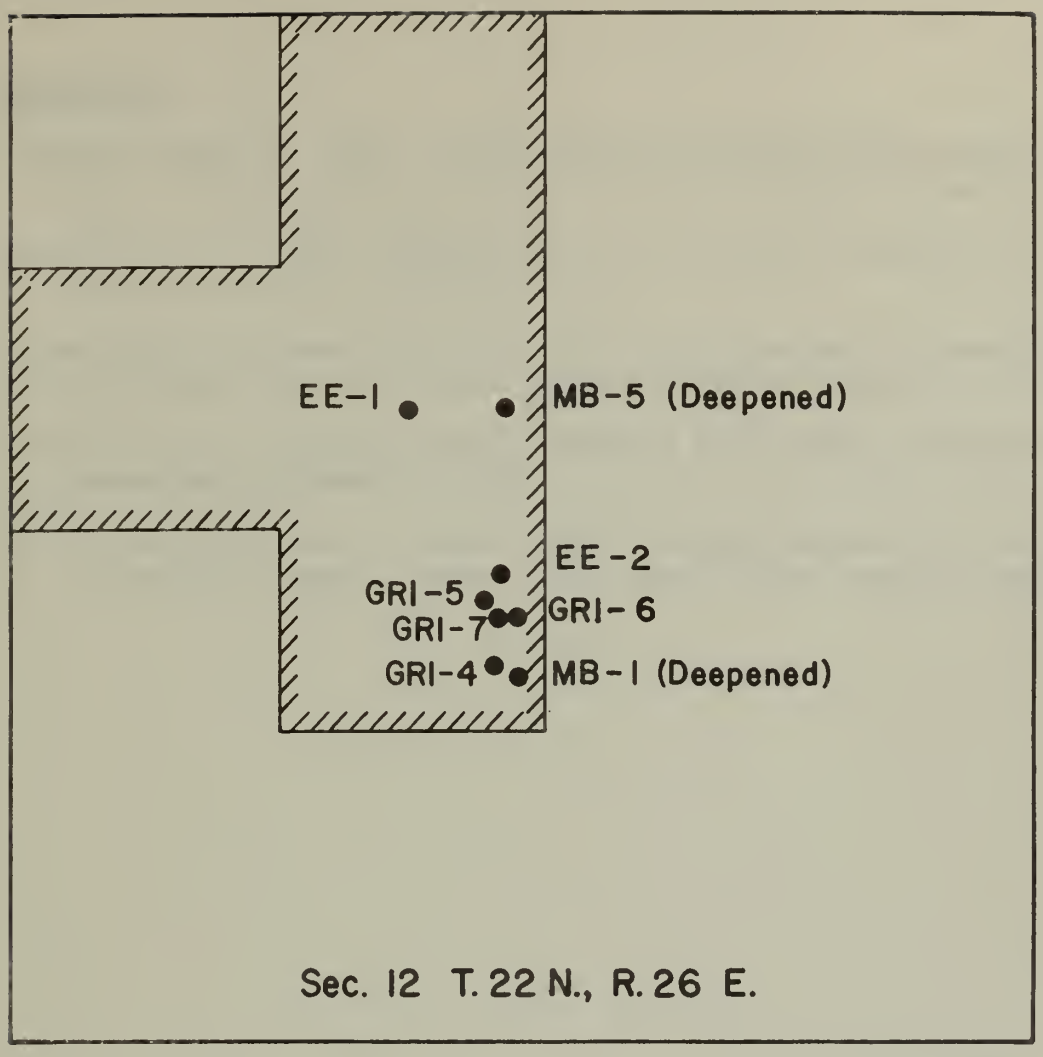
The deep well (5,050 feet) was drilled by Earth Energy Inc. in 1964 and, for testing, a 4-1/2" liner was landed at 5,050 feet with slotted perforations from 4,820 to 5,050 feet. On a production test, this well flowed 120 gallons/minute of fresh water with steam at 210°F (surface temperature). The hole was later plugged and abandoned.

Currently exploration activity has increased. Several companies have engaged in geophysical prospecting and thermal gradient measurements in the general Brady's Hot Springs area.

Phillips Petroleum Company is just completing an 8,000 foot, 12 inch in diameter, well on private land in Section 29, T. 22 N., R. 27 E. and the Union Oil Company is drilling a 5,000-6,000 foot well about a mile north of Brady's Hot Springs on private land.

GEOTHERMAL WELLS - BRADY'S HOT SPRINGS
CHURCHILL COUNTY, NEVADA

OPERATOR	WELL	LOCATION SEC.	T.	R.	SPUD	TOTAL DEPTH	COMP. OR ABD	MAX. TEMP. °F.	SURFACE TEMP. °F.	REMARKS
Magma Power Co.	Brady #1				1959)					) 1031' total footage--
Magma Power Co.	Brady #5 (?)				1959)	No data available				) both wells
					)					) Steam zone 341° @ 45 psi
Geothermal Resources Inc.	Brady #4	12	22N	26E	6/19/61	723'	Susp.7/25/61	340°	285°	19,600 lbs./hr. steam + 262,000 lbs./hr. @ 285°F.
Geothermal Resources Inc.	Brady #5	12	22N	26E	7/26/61	192'	ABD 8/17/61	252°	--	ABD - Lost tools in hole.
Geothermal Resources Inc.	Brady #6	12	22N	26E	8/18/61	770'	Susp.10/30/61	320°	--	Susp. - Never produced.
Geothermal Resources Inc.	Brady #7	12	22N	26E	10/31/61	250'	ABD 11/9/61	220°	--	ABD - Never tested.
Earth Energy Inc.	Brady #1	12	22N	26E	11/6/64	5050'	ABD 12/13/64	414°	194°	Flowed 120 gal./m (4114 B/D) Fresh water with steam at 210°F.
Earth Energy Inc.	Brady #2	12	22N	26E	4/22/65	282'	Susp.5/5/65	?	?	
Earth Energy Inc.	Magma Brady #1	12	22N	26E	R.5/12/65	1567'	Susp.5/20/65	212°	?	Deepening
Earth Energy Inc.	Magma Brady #5	12	22N	26E	Res.5/21/65	1800'	C. 5/25/65	341°	281°	Deepening from 500'



Scale 1"=1000'

Private Land
Geothermal Well
MB Magma Power Co.
GRI Geothermal Resources Int.
EE Earth Energy Inc.

Geothermal Wells
Brady's Hot Springs

Churchill County, Nevada

(D) References

Axelrod, Daniel I. 1956. Mio-Pliocene floras from west-central Nevada. Univ. of California Publications in the Geological Sciences, Vol. 33.

Lincoln, F. C. 1923. Mining districts and mineral resources of Nevada. Nevada Newsletter Publishing Co.

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Southern Pacific Company. 1964. Minerals for industry, northern Nevada and northwestern Utah.

Wilden, Ron and Robert C. Speed. 1968. Geology and mineral deposits of Churchill County, Nevada. U.S. Geol. Survey Open File Report.

Stages of Implementation

Four separate stages of implementation have been identified:

I) Exploration
II) Development
III) Operation
IV) Close-out

The progression from one stage to the next is dependent upon the success of each earlier stage. In practice, one stage often blends into another and it would be common for exploration and development to be undertaken in one part of a geothermal field, while a production operation was going on in another part of the field. Close-out of some wells, including rehabilitation, might also be taking place at the same time.

EXPLORATION

Exploration includes all activities from the decision to explore for a geothermal field through the drilling of one or more "wildcat" (exploratory) wells.

Operations conducted under an approved "Notice of Intent to Conduct Geothermal Resource Exploration Operations," (43 CFR 3209) cover any surface disturbing techniques up to and including the drilling of shallow temperature gradient holes. Such operations do not include, however, the drilling of core holes for geologic information nor the drilling of "wildcat" geothermal wells.

Operations conducted under a geothermal lease (both competitive and non-competitive) include all exploration actions.

For convenience, exploration activities (as they relate to surface damage) may be classified into five discrete operations, four of which require physical presence on the land. They are:

(A) Airborne exploration
(B) Off-road vehicular travel
(C) Road and trail construction
(D) Drilling
(E) Rehabilitation

In practice, several of these operations may be going on concurrently. The technique is to start by evaluating large areas (i.e. several townships) and gradually reduce the area of interest to select a target for drilling. As the area of interest shrinks, more intensive exploration techniques are employed.

(A) Airborne Exploration - This involves a series of techniques including:

(1) Aerial photography - for geologic interpretation.
(2) Imagery - infared to detect heat differentials; microwave to detect soil moisture differentials.
(3) Magnetic - airborne magnetometer measures variations in the magnetic intensity of the earth.
(4) Gravity - airborne gravimeter measures differences in the specific gravity of the earth.

All of these techniques are attempts to gain data on the subsurface geology of an area. The data gathered must be interpreted by specialists and may supply clues as to areas deserving of more detailed studies.

Airborne exploration produces no surface disturbance. It creates only a temporary negligible impact on air quality and noise levels.

(B) Off-Road Vehicular Travel - Many exploration techniques require off-road vehicular travel in various degrees. Generally, existing roads are used where possible. Techniques which sometimes require cross-country travel include:

(1) Geological mapping - One or more small vehicles transport geologists to the work area.

(2) Geophysical exploration - Includes a number of techniques seeking clues as to underground geology:

Gravity - Ground gravity surveys involve obtaining gravity readings along a surveyed grid with a portable gravimeter. A three-man crew does the work (two survey and the third records gravity readings). One or two small trucks transport the crew and equipment to the work area.

Magnetic - Magnetic variations are measured with a magnetometer. The field technique is similar to the gravity determination.

Seismic - Elastic shock waves are generated and measured along a grid system (generally 1-2 mile grid). Receivers (geophones) pick up elastic waves generated at a specific point on the grid. The elastic waves are generated by one of three methods:

Vibration method - Vibrations are produced by truck mounted vibrators, usually four, which operate in unison.

Thumping method - A truck-drawn or self-propelled unit containing a heavy weight or "hammer" drops the hammer on the ground to produce shock waves.

Explosive method - A truck-mounted rotary drill is used to drill holes 100-200 feet deep. These holes are loaded with 5-50 lbs. of explosives and detonated (shot) to produce the elastic waves.

In all three seismic methods, 5-7 trucks and 10-15 men are required. Surface mineral matter and vegetation must be removed from the energy generation sites (shot points) and receiving sites (geophones) to provide for the maximum amount of energy to be sent and received. In addition, the explosive method often requires road construction, blading of lines and clearing of small areas for drill operation.

All three seismic methods involve varying degrees of surface disturbance. The explosive method produces the most intense surface disturbance. Only the explosive method possesses the potential for subsurface impact (damage to nearby water wells, damage to near-surface aquifers, etc.), and then, only within a limited radius of the shot point.

Microseismic - Small geophones called seismometers are buried at a shallow depth and transmit normal extremely minor seismic activity (micro-earthquakes) to an amplifier on the surface. The amplifier is about the size of a suitcase. Locations are set up away from roads to avoid traffic "noise." These units are often backpacked into areas inaccessible to vehicles.

Resistivity - Induced Polarization (IP) techniques are used to measure the resistance of subsurface rocks to the passage of an electrical current. A vehicle mounted transmitter sends pulses of electrical current into the ground through two widely spaced electrodes (usually about two miles apart). The behavior of these electrical pulses as they travel through underlying rocks is recorded by "pots" (potential electrodes), small ceramic devices that receive the current at different locations. The electrodes are either short (2-3 feet) rods driven into the ground or aluminum foil shallowly buried over an area of several square feet. Two or three small trucks transport the crew of 3 to 5 men to transmitting and receiving sites.

Telluric - A string of "pots" (potential electrodes) record the variations in the natural electrical currents in the earth. No transmitter is required. Small trucks are used to transport the crew to the work area.

Radiometric - Radioactive emissions (generally radon gas) are measured as an indication of subsurface steam. Such measurements are usually made in the vicinity of hot springs, hence existing roads are generally used. Measurements are taken with a hand held scintillometer.

(3) Geochemical surveys - Includes the sampling of spring water to determine dissolved solid content (acidity, Na/K ratio and silica content) and the taking of small (hand trowel) surface soil and rock samples on a grid system to determine introduced mineralization and source areas for recharge. Occasionally small trucks are used to transport the crew (usually 2-3 men) and equipment to the work area.

(C) Road and Trail Construction - For exploration activities utilizing large equipment in rough terrain with poorly developed access, roads and trails are often constructed. Since they are intended to provide only temporary access for such equipment as small drilling rigs and water trucks, they are usually constructed to a very low standard--generally a 10-foot wide dozer trail is used in dry, stable country. Where larger drilling equipment is to be used for an exploratory (wildcat) well, a considerably higher road standard may be employed.

(D) Drilling - Several types of drilling are utilized in the exploration phase including seismic test holes, temperature gradient holes, geologic or strategraphic information holes, and exploration wells. The size of the equipment and the surface area needed differs with each. The type of drilling used is rotary drilling which employs the principle of a rotating vertical pipe (drill stem) upon which has been mounted a rock bit designed to chip rock as it rotates under pressure.

Drill cuttings or chips produced as the hole progresses are removed from shallow shot-holes by introducing a jet of air during drilling. For deeper drilling, a circulating medium of water or mud (a suspension in oil or water of various finely-divided substances, each possessing specific properties) is pumped down the inside of the drill pipe and allowed to return up the annular space between the hole wall and outside of the drill pipe. This circulating medium is used to cool and lubricate the bit as well as to return the drill cuttings to the surface. Drilling mud helps prevent caving by plastering and consolidating the walls of the hole with a clay lining, thereby making casing unnecessary during shallow drilling.

(1) Seismic test holes - Shallow holes 100-200 feet deep are drilled with small truck-mounted rigs. Cuttings are removed by compressed air. The surface area used is just sufficient for the truck and equipment. An area of about 30 x 30 feet is disturbed by the operation. No specific drill pad is built.

(2) Temperature gradient holes - Shallow holes 300-500 feet deep are drilled with a small truck-mounted rig. The holes are usually between 4 and 6 inches in diameter. Mud is employed to remove the cuttings, and generally a portable metal mud pit is used to contain the mud. An area of about 30 x 30 feet is disturbed by use of the drill rig and servicing water truck.

Upon completion of the temperature gradient hole a capped pipe (usually 3/4 inch diameter) is placed in the hole, stand for about a week. Water in the pipe is heated by the temperature of the surrounding rock. Because of the small diameter of the pipe, convection currents do not form, hence the water temperature in the pipe varies with depth. The temperature at different depths is measured by a thermister probe on a cable.

(3) Geologic information holes - These holes are similar to those drilled for temperature gradient purposes. Larger equipment is employed and a surface area of about 40 x 60 feet may be used. The cuttings are examined and the hole is probed with geophysical instruments to acquire data on the rock types and structure. Because these holes may extend to 1000 feet or more, a larger mud pit is needed. Typically, a mud pit is scooped out with a bulldozer. These pits may be 10-20 feet wide by 30-50 feet long by 3-6 feet deep depending on the terrain and the depth of the hole.

(4) Exploration wells - These wells are the same as development and production wells. If successful, they are generally converted to production. Drilling equipment, technology and methods are similar to those used in oil and gas operations. Well bores of up to 24 inches in diameter may be drilled to depths of 5,000-10,000 feet.

Mud is generally used for the drilling. Where water flows are not encountered, compressed air may be substituted as the circulation medium. At the Geysers dry steam field, for example, mud is used to the depth that temperature interferes with proper operations, then compressed air is used. Noise created during the air drilling operation is intense and approximates that of an unmuffled diesel truck.

A drill pad is leveled and cleared of vegetation. This generally involves a surface area of from less than one acre up to two acres. The ancillary equipment is generally also located on the drill pad. A reserve pit of approximately 1,000 to 10,000 square feet and 6-8 feet deep is sometimes dug to contain waste fluids and drill cuttings during drilling operations.

The well is cemented and cased and a blow-out preventer is installed to control sudden surges of pressure.

Blow-outs are uncommon, but do occur. The basic problem is a lack of knowledge of the specific characteristics of a geothermal field. During the pioneering development in many fields around the world, blow-outs seem to have occurred in 1-3% of the test and production wells drilled. At the Geysers there have been three blow-outs with over 100 wells drilled. Landslides in that steep terrain caused much of the problem. Geothermal blow-outs cause no fire hazard and are generally controlled by slant drilling and sealing with concrete.

While the blow-out is taking place, water, steam and contained elements are wasted and spread on the surrounding land.

The release of pressure and water through drill holes may affect the surface expression of the geothermal field. Springs and geysers may dry up, may be renewed in a different place, or may be increased. Accurate prediction of the results of drilling on such surface features cannot be made.

Since geothermal reservoirs are typically in active fault areas, normal earthquakes also occasionally change the surface features by drying up, moving or increasing thermal activity. It is thus not always possible to determine whether the observed effect was caused by drilling or by natural action.

(E) Rehabilitation - Rehabilitation activities vary with terrain, climate, and significance of the damage.

(1) Off-road vehicular travel. Generally no rehabilitation is undertaken because the disturbance is temporary and, in most areas, heals itself in a short time.

(2) Road and trail construction. Generally no rehabilitation is undertaken unless there is a definite requirement for it (i.e. erosion hazard, access where none is wanted, etc.). Where needed, such roads and trails can be scarified and reseeded if the site is susceptible to revegetation.

(3) Drilling. Small drill hole sites (seismic test holes, temperature gradient holes, informational holes) are usually rehabilitated by cleaning up any debris and smoothing the area with a bulldozer where needed. Mud pits are filled and leveled. Where climate and terrain permit, revegetation could be accomplished.

Large exploratory wells are capped with a pressure head ("Christmas tree") to prevent blow-outs, and typically left in operating condition. Other structures are removed and the drilling pad may be revegetated if climate permits.

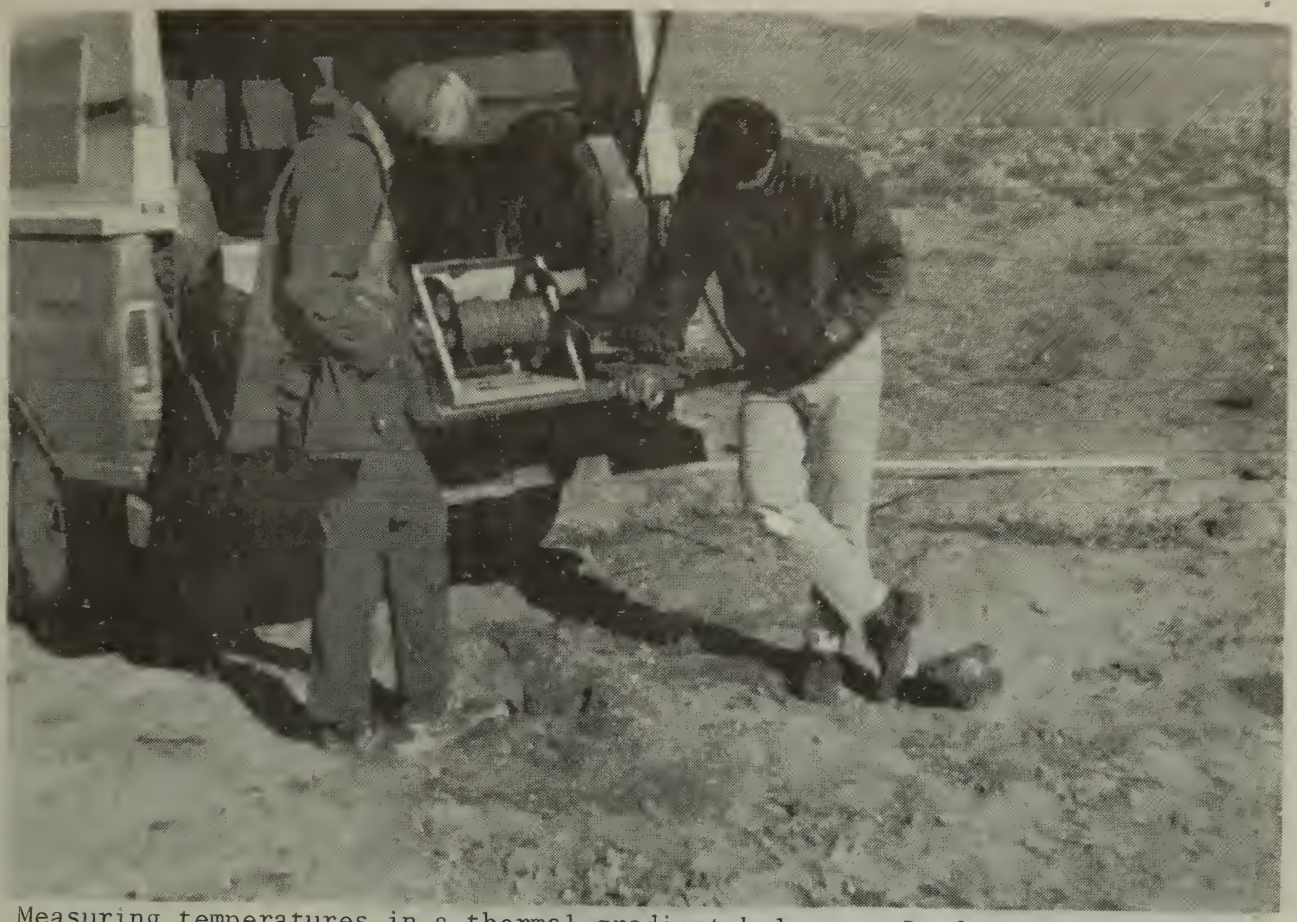
Resistivity survey near Brady Hot Springs. Gasoline generator is at right and transmitter is visible in the truck.

Setting a "Pot" (potential electrode) to receive signals from the transmitter during a resistivity survey.

Off-road travel near Brady Hot Springs. Tracks made by resistivity crew are less than one week old.

Typical road constructed for drill rig for temperature gradient holes near Brady Hot Springs.

Drilling a 200-500 ft. temperature gradient hole near Brady Hot Springs. Note metal mud sump at center.



Measuring temperatures in a thermal gradient hole near Brady Hot Springs.

Close-up of thermister cable in 3/4 inch, water-filled pipe that goes to the bottom of the hole.

Typical mud pit dug for a 1,000 foot informational hole. Such pits are used because the metal sumps are too small to hold the amount of mud needed for such a deep hole.

Partially reclaimed thermal gradient hole near Brady Hot Springs. Julia Elfving is standing at the hole location. Note the site attracts cattle.

Reclaimed thermal gradient hole about three months after reclamation. Julia Elfving is standing at the hole location.

DEVELOPMENT

Development includes all activities from the decision to develop a producing field until commercial power generation and transmission is reached. These operations are conducted only under a geothermal lease (either competitive or noncompetitive).

Five discrete operations, as they relate to surface disturbance, are recognized:

(A) Road development
(B) Drill site development
(C) Geothermal pipelines
(D) Plant construction
(E) Transmission lines
(F) Rehabilitation

Many of these operations would normally be taking place concurrently.

(A) Road Development

During development, roads to drill sites, power plant sites, and along transmission line routes may be constructed. Roads to producing wells and power plants will be permanent and may be surfaced and stabilized. Culverts will be utilized to avoid erosion of the road bed where necessary. Temporary roads to drill sites and for construction of power lines will generally be built to a low standard.

(B) Drill Site Development

Wells drilled during the development stage will be similar to exploration wells. Often, somewhat larger equipment is used. The drill pad is leveled and cleared of vegetation. Generally from less than one up to two acres are disturbed. A reserve pit (sump) 1,000 to 10,000 square feet and 6-8 feet deep is sometimes dug to contain waste fluids during the drilling operations. The sump may be fenced to keep out animals.

(1) Water - About 500-1,000 barrels (1 barrel = 42 gallons) of water per day will be used in drilling a well. This water may come from water wells drilled in the immediate vicinity (about 60 gpm flow would be adequate), from nearby surface water, or it may be hauled in by truck.

(2) Spacing - Current geothermal plants require a steam pressure of about 100 PSI at the generator. This places a limit on the distance steam can be piped to the generator because of heat loss. Wells are therefore generally located within one-half mile of the generation plant. The number of wells used to service a plant is dependent on the temperature of the wells (a temperature of 325-350^{o}F at the generator is needed) and the characteristics of the geothermal reservoir. Generally, from 16 to 20 producing wells are used per power plant.

At Cerro Prieto, 18 wells (3 are standby) will service a 75 MW generating plant. They are drilled on a 10 acre spacing (one well per 10 acres). A 40 acre well spacing is being used at the Geysers initially, but future infill drilling to 20 acre spacing is planned in order to maintain steam production to plant capacity.

(3) Production Testing - To determine the sustained flow characteristics of a well, and to clean out the hole, each new well is vented to the atmosphere for a period of time. At the Geysers, enough experience has been gained as to the characteristics of the reservoir that this is no longer necessary there. Elsewhere it is an established practice.

Steam, water and noise accompany production testing. The water is generally directed into the reserve pit and is contained. The steam is released into the atmosphere.

Noncondensible gases (carbon dioxide, methane, hydrogen, nitrogen, argon, carbon monoxide, hydrogen sulfide, radon, ammonia) and vapors (boric acid and mercury) are often contained in the steam. These vapors and gases make up generally less than 3% of the total steam fraction.

When present in excessive amounts, some of these gases and vapors are toxic.

Gas	Toxicity Levels
Ammonia	50 ppm
Boric acid	None established
Carbon dioxide	5,000 ppm
Carbon monoxide	100 ppm
Hydrogen sulfide	20 ppm
Mercury	12.2 ppb
Methane	10,000 ppm

Where present in unacceptable amounts, monitoring devices and special precautions may be necessary as a safety measure.

Additionally, very small amounts of hydrogen sulfide (as small as .025 ppm) can be detected by smell. This "rotten egg" odor, common in hot spring areas, can be an aesthetic problem.

High noise levels accompany production testing. Because of this, muffling devices are generally installed. At the Geysers measurements of noise from a muffled testing well indicates a noise level slightly less than that of an unmuffled diesel truck.

Noise levels from other geothermal fields, both vapor dominated and water dominated, may not be of a similar magnitude.

(4) Blowouts - In the four geothermal areas in the world (Geysers, USA; Lardarello, Italy; Wairakei, New Zealand; Cerro Prieto, Mexico) which have undergone commercial development, blowouts have occurred in approximately 1-3% of the wells drilled. These blowouts were mostly in the exploratory or early stages of development drilling, with few mishaps in later stages as experience was gained and local drilling techniques perfected. Although some of these blowouts were temporarily spectacular, none have resulted in any significant or lasting environmental damage.

At Lardarello, Italy, the oldest commercial geothermal field in the world, they are routinely handled as a noisy, difficult part of regular operations. They are not considered as serious mishaps that could cause pollution or have other adverse effects.

(C) Geothermal Pipelines

Pipelines 10 to 30 inches in diameter will be used to transmit steam or hot water from the production wells to the power plants. The pipes are typically insulated with fiberglass or asbestos to minimize heat loss. Expansion loops or joints are placed at frequent intervals either vertically or horizontally to provide for the extreme expansion and contraction of the pipes upon production startup (heating up) and shutdown (cooling down).

Under present technology, pipelines are constructed above ground to provide for expansion and contraction and to enhance maintenance and detection of leaks. Underground installation is thus far uneconomical and may also present some safety hazards.

The lines form a radiating pattern on the surface, connecting wells with the power plant. They may be painted to blend with the surroundings.

(D) Plant Construction

Generating plants are centrally located to minimize the length of the steam or water pipes from the servicing wells. The largest plants in current use consist of two 55 MW generators housed together so that production is 110 MW per power plant. Power plant spacing is about one plant per 640 acres throughout the productive area.

At the Geysers, the average 110 MW plant building is about 100 x 200 feet and three stories high. The adjacent cooling towers are about a third larger than the generating plant building. The entire generating plant-cooling tower complex occupies an area of about five acres.

(E) Transmission Lines

Power generated from the plant is transmitted via conventional power lines to the area of use. The size and location of the lines is dependent upon the power output and destination.

The lines will tend to be large, considering that 1 MW of plant capacity will service the power needs of about 1,000 people. To express this another way, one 110 MW power plant could supply the power needs of the City of Reno.

(F) Rehabilitation

Rehabilitation will be possible on disturbed areas not needed for continued production, commensurate with terrain, climate and significance of the damage.

(1) Road Development - Roads needed for maintenance and further development will not be rehabilitated. Temporary roads and trails can be scarified and revegetated, if desirable.

(2) Drill Site Development - After well completion, an area approximately 30 ft. x 30 ft. directly surrounding the well head will be needed for operation. An additional graded area about 50 x 100 feet may be needed for moving in a drilling rig to correct any problems which may develop during production. The reserve pit (sump) is generally dried out, covered with dirt, and graded. It and the remaining area of the drill site can be rehabilitated and revegetated.

(3) Plant Construction - The area disturbed in constructing the generating plant and cooling towers can be rehabilitated and revegetated. The buildings may be painted to blend with the surroundings. Some cooling towers are architecturally attractive and, if desired, may be intentionally painted to contrast with the surroundings to heighten the visual experience.

(4) Geothermal Pipelines - Geothermal pipelines may be painted to blend with the surroundings and any areas not needed for access may be revegetated. At Lardarello, Italy, steam lines cross grainfields and vineyards with essentially no loss of land productivity.

(5) Transmission Lines - Surface disturbance accompanying electrical transmission line construction may be rehabilitated with the exception of needed maintenance roads.

Exploration well drilled by Geothermal Resources International at Mono Lake, California. The same equipment would be used for development and production wells.

Development well being drilled at Cerro Prieto, Mexico.

Exploration well near Beowawe, Nevada being drilled by Chevron Oil Company and American Thermal Resources to a planned depth of 10,000 feet.

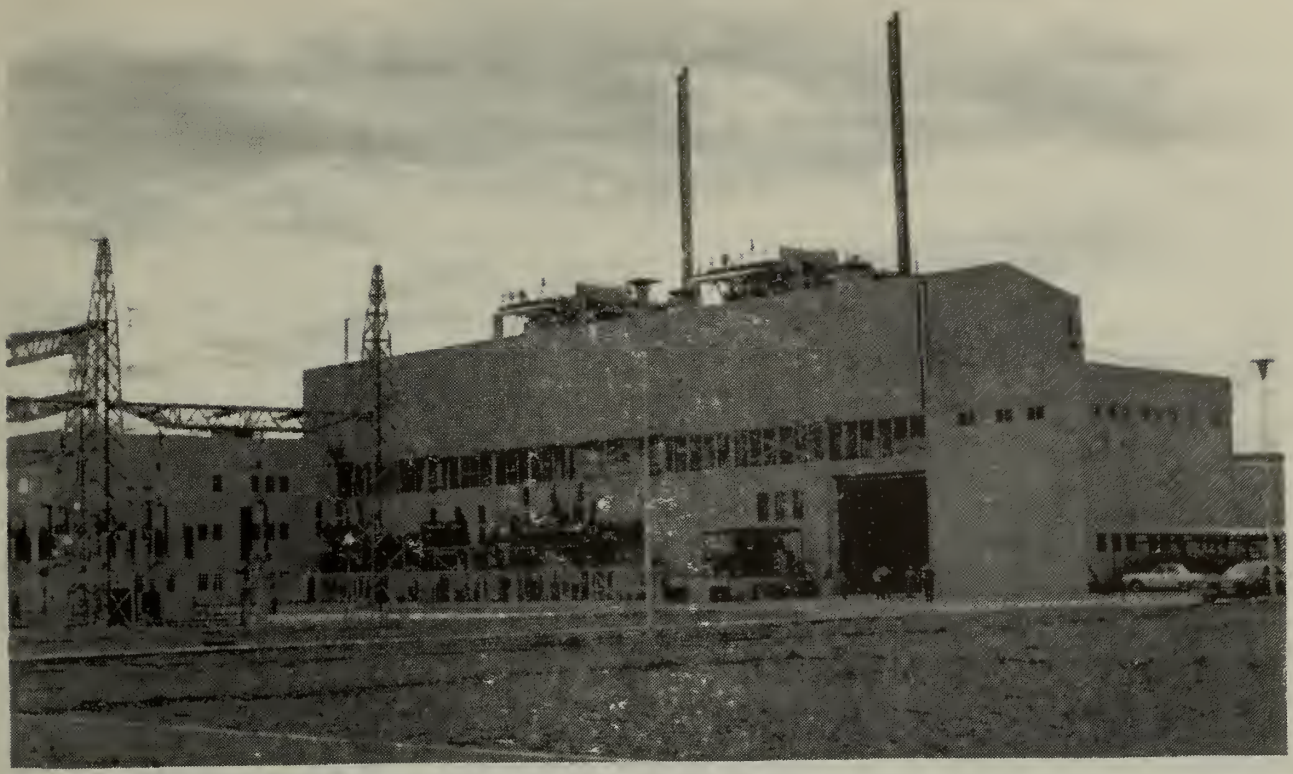
Water dominated geothermal well at Cerro Prieto, Mexico. Superheated water rises through the series of control valves ("Christmas tree") at the well head to the large expansion chamber (cyclone separator) at left. There it flashes into steam and the steam portion is drawn off through a vertical pipe which comes out the bottom of the separator and piped to the turbine. The water fraction goes from the separator via the pipe at far left to muffling devices (silencers), and then to the evaporation ponds.

Geothermal pipelines at Cerro Prieto, Mexico. Note well in left center--the steam is rising from two muffling devices (vertical silencers).

Geothermal pipelines at Lardarello, Italy crossing cultivated fields and vineyards.

Power plant and cooling towers at the Geysers, California. Geothermal steam pipelines in the foreground.

Power plant at Lardarello, Italy. Note the esthetically pleasing architectural design of the large, natural draft cooling towers.



Cerro Prieto, Mexico power plant houses two 37-1/2 megawatt generators for a total of 75 MW capacity.

Cooling towers at Cerro Prieto.

OPERATION

The operation phase starts upon reaching commercial power production. Exploration and development are typically carried on in other parts of the geothermal field simultaneously with the operational activities.

The operation stage may be divided into the following discrete operations:

(A) New drill sites
(B) Maintenance
(C) Waste disposal
(D) Production

(A) New Drill Sites

Geothermal fields are long lived resources. The Lardarello field has been in production since 1904 and the Geysers since 1958. The Geysers is estimated to have a minimum productive life of 30 more years. Nonetheless, production slowly diminishes the heat flow and additional wells must be drilled and completed to keep the generating plant operating at full capacity.

Additional wells may also be required to replace wells that have become inoperative and, if the waste waters are disposed of by injection, injection wells may be drilled.

The technique and effect of these wells would be the same as for development wells. On a major producing field, it can be expected that one or two drilling rigs would be operating continuously throughout the life of the field drilling additional or replacement wells.

(B) Maintenance

Repair, maintenance and monitoring of an operating field will require the periodic use of access roads to service the equipment. Existing wells will require occasional repair work or cleanout. The amount of this remedial work will depend upon the production characteristics of the field; severe scaling and corrosion would require frequent remedial work. Normally, one medium-sized drill rig would be required full-time for each 20-30 wells (one 110 MW power plant).

(C) Waste Disposal

The work force (both construction and maintenance) for geothermal power plant will usually be housed in the nearest town rather than creating a new town at the site. Thus, waste materials connected with human habitation will typically be handled in the local community.

At the plant site itself, sanitary facilities for workers will be provided. Solid wastes will either be disposed of in a dump developed at the site or trucked to the nearest established dump site.

The most significant waste disposal problem relates to handling the excess geothermal fluids. In vapor dominated systems, as at the Geysers,

about 75-80% of the water from the spent steam is consumed in the cooling towers, leaving 20-25% to be disposed of. In water dominated systems, such as Cerro Prieto, the reverse is true with 80% or more of the total well production requiring disposal.

Disposal techniques vary, depending on the quality and quantities involved. Any or a combination of the following techniques may be employed:

(1) Evaporation ponds - Waste water at Cerro Prieto is piped to evaporation ponds. Where water quality is satisfactory, such ponds may provide new aquatic habitat. Where water quality is toxic, special measures may be required to protect the groundwater supply, livestock and wildlife.

(2) Natural drainage systems - At Wairakei, New Zealand, waste water is discharged into a large river. High quality water disposed of in this manner provides additional resources for agriculture, wildlife and other uses. Low quality water may require extensive treatment before it is suitable for release into natural drainages.

(3) By-product development - In some instances it may be economical to extract useful minerals or gases from the geothermal fluids. This could result in increasing the waste water quality so as to make it available for other purposes. Desalinization may also be feasible in some areas, providing by-product fresh water for other uses.

(4) Re-injection - At the Geysers, excess water is re-injected into nonproductive zones of the geothermal field. Successful re-injection is dependent on the quality of the waste water and the geologic characteristics of the geothermal field. Typical considerations would include: whether plugging and scaling problems will prevent the reservoir from accepting the fluid; whether fresh water aquifers can be adequately protected from contamination by hot saline waste water; and whether the sub-surface rock structure will adequately hold the re-injected fluids.

(D) Production

Production from a geothermal field will generally require 2-5 people per plant to inspect, adjust and service the wells, making the rounds about once each day on the existing road network.

Sustained production will have several effects:

(1) Temperature drop - The field will gradually realize diminishing temperatures as the energy is utilized.

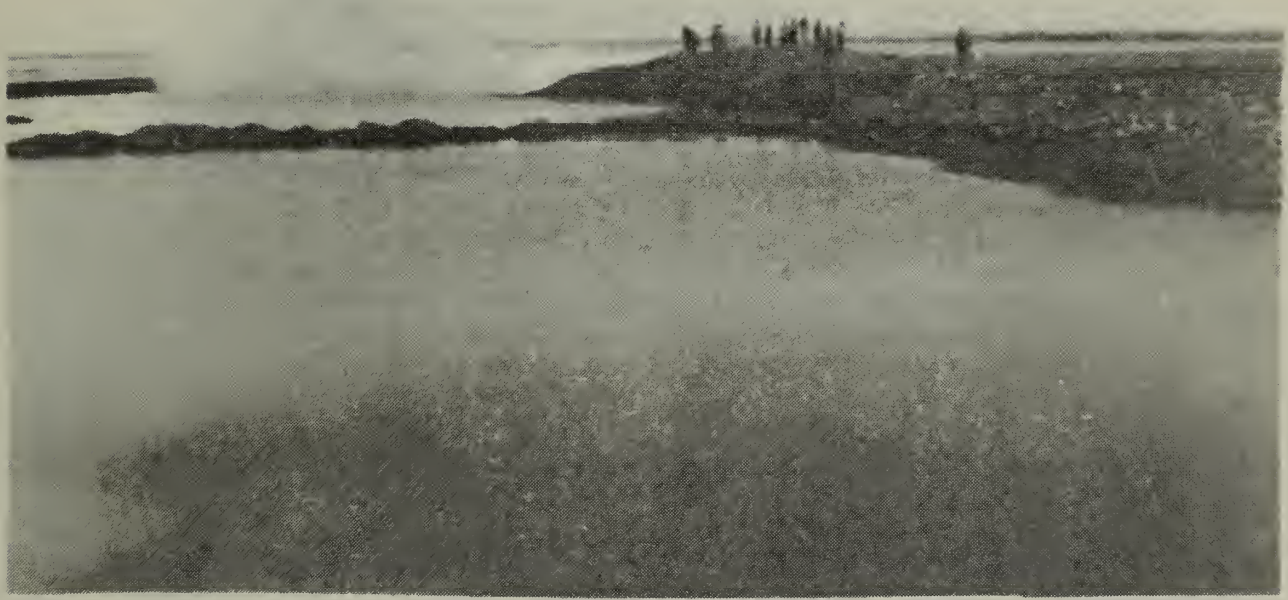
(2) Water utilization - Cooling towers will consume about 40-45 acre feet of water per year for each megawatt of plant capacity. Each 110 MW plant would thus consume about 5,000 acre feet of water per year. The water may come either from steam condensate, waste geothermal water, or from any other water source. This water consumption might be reduced by use of some technique other than conventional cooling towers. One such scheme, called the "night stream cooling system" would theoretically use only 42% as much water.

(3) Subsidence - As large volumes of water are pumped from a geothermal reservoir, some subsidence of the ground surface may occur. In many cases subsidence may have no serious land use or environmental consequences. In some situations, such as developed agricultural land under gravity irrigation, minor surface subsidence could have a significant impact. Continuous monitoring might be necessary to detect whether subsidence was occurring. In some instances, re-injection of the waste water might correct subsidence problems.

(4) Seismic activity - Geothermal areas are typically associated with seismic activity. Such activity is generally of small magnitude (usually less than 4.5 on the Richter scale). Fluid pressure changes from both production and re-injection may tend to increase earthquake frequency, though the relationship is not well known. To date, such earthquakes have been small and there is some evidence to suggest that this minor seismic activity tends to relieve regional stresses and diminishes the likelihood of large earthquakes. Earthquakes sometimes modify geyser activity and may effect other geothermal features such as hot springs.

Old geothermal well at Brady's Hot Springs, Nevada showing buildup of calcium carbonate in pipe. Such scaling causes maintenance problems.

Calcareous sinter (travertine) at Fly Geyser, Nevada deposited by a flowing well. Such contained salts affect the uses to which excess water may be put.



Discharge of excess fluids at Cerro Prieto, Mexico. About 80% of the water production is excess and is piped to these large evaporation ponds. The discharge is rather noisy but not intolerable--note the crowd observing the operation.

CLOSE-OUT

Close-out or final abandonment takes place when energy production ceases to be economic. To date, no developed geothermal field has reached this stage. In a sense, geothermal reservoirs may be somewhat renewable resources in that after a long period of rest, the fluids may become re-heated to temperatures that are again useable.

Two discrete operations are expected to take place during close-out:

(A) Removal of improvements
(B) Restoration of surface

(A) Removal of Improvements

The removal of improvements from a geothermal field involves:

(1) Surface improvements - Removal of all structures constructed during field development and operations will be accomplished. Solid waste remaining may either be disposed of in a dump developed at the site or trucked to the nearest established dump.

(2) Wells - The bottom of the hole is plugged with cement and the surface casing will also be plugged with about 20 feet of cement. The casing will be cut off below the surface and a steel plate welded over the hole. A vertical steel pipe and marker will be welded to the plate. The concrete lined excavation surrounding the hole (called the "cellar") will be pushed in and the location may be graded and revegetated. The marker will remain above ground to provide identification.

(3) Transmission lines - Any of the electrical transmission lines no longer in use will be removed.

(B) Restoration of the Surface

Surface restoration will typically be a gradual process, taking place throughout the life of the field and culminating with the final abandonment. Access roads can be ripped up, landscaped and revegetated. Power lines can be landscaped and revegetated. Well and plant locations can similarly be treated but, because of their larger size, complete landscaping to approximate the original surface in steep terrain will not be feasible except in unusual circumstances.

Environmental Controls

Geothermal energy development is subject to a wide variety of environmental controls under the authorities of two agencies--Geological Survey and BLM. Such environmental controls are covered in the regulations of both agencies (GS - 30 CFR 270; BLM - 43 CFR 3200) and are part of the exploration form (3200-9) and lease form (3200-21). Additional controls in the form of special stipulations, geothermal resources operational orders (GRO orders), and approved operational plans may also be used. Bonding is required to assure compliance.

Basically, the two agencies consult throughout the leasing program and agree on any needed special stipulations. For all actions up to and including issuance of a lease, the BLM is the responsible agency. For all operational activities undertaken after a lease has been issued, the Geological Survey is the responsible agency.

Opportunities to attach special environmental controls occur at several points:

(A) Notice of Intent to Conduct Geothermal Resource Explorations - (Form 3200-9) - This form is filed for exploration activities not connected with a lease. The BLM District Manager has 30 days to either approve or disapprove the permit. Special stipulations may be added if needed. The Geological Survey will advise of any recommended stipulations to protect subsurface resource values. A $5,000 compliance bond is required.

(B) Proposed Plan - Prior to the issuance of a lease, the applicant must file a proposed plan detailing his proposed methods for diligent exploration. Environmental protection measures proposed are included. The proposed plan may alert the District Manager to special problems that should be covered by special stipulations in the lease. The Geological Survey will also review these plans and may furnish additional comments or information which may be useful for environmental considerations.

However, these proposed plans are filed so early in the process that they will generally be based on little knowledge of the available geothermal resource and, hence, will usually undergo major changes as new exploration data is gathered. They will tend to be written in broad general terms commensurate with the limited data available. Therefore, they cannot be entirely relied upon in anticipating environmental effects.

The chief value of the proposed plan is to commit the applicant to a program of diligent exploration. Reliable environmental judgments can be made later when an actual plan of operation is filed.

(C) Leases - Lessees are committed to a variety of environmental controls by regulation and the standard lease (Form 3200-21) contains stipulations on protection of the environment and antiquities.

Additionally, special stipulations may be added if necessary. The Geological Survey will provide advice as to recommended special stipulations to protect the subsurface environment and as to the effect of any proposed BLM special stipulations on geothermal development.

Two bonds are required: a $10,000 bond to insure lease compliance, and a $5,000 bond to indemnify any damages to persons or property. A $150,000 nationwide bond or $50,000 Statewide bond may be substituted.

(D) Geothermal Resources Operational Order (GRO Order) - The Geological Survey issues GRO orders which set forth the requirements and procedures to be followed within a particular region or area. This allows flexibility to address conditions which vary widely from area to area. The BLM District will be consulted by Geological Survey to develop any needed surface resource protection requirements.

(E) Plan of Operation - Before any operations may commenct on a lease, the lessee must submit a detailed plan of operation and gain approval of it. Both the Geological Survey and the BLM must approve it.

In practice, these plans will tend to be incremental with new phases of the plan based on information gained in the preceding phase. They will be detailed enough to allow a sound environmental assessment prior to approval.

Energy Considerations

U. S. energy demand is expected to continue increasing at a rate of 3-5% per year. To keep pace, we shall either have to import more fuel (imports are currently about 4%) or develop more domestic sources. President Nixon has stated that our policy goal is to become independent in energy resources by 1980.

All forms of energy supplement one another in the total energy picture. Should geothermal energy be used to produce electricity, other forms of energy (coal, oil, gas) would be freed for use elsewhere.

Estimates of our geothermal potential vary widely but suggest that by the year 2000 such energy may supply 5-14% of our use. This is a significant amount considering that hydroelectric power currently supplies only about 5% of the total.

Geothermal energy offers less environmental impact than conventional energy sources. Essentially all of the impact, with the exception of power lines, is confined to a small site. Other power forms have multiple impacts: power dams flood large acreages; coal, oil, gas and nuclear sources are mined in one place, transported to another place where power is generated and then transmitted via power lines to the area of use.

In the short range, geothermal sources stand a far better likelihood of substantial contributions to the energy pool than do such exotic sources as solar energy, breeder and fusion reactors, fuel cells, etc.

Economic Considerations

There are several ways to view the economic implications of geothermal development:

(A) Direct revenues
(B) Indirect revenues
(C) Direct expenditures
(D) Indirect expenditures

(A) Direct Revenues

Lease rentals and royalties are distributed as follows:

95% - U. S. Bureau of Reclamation
5% - State of Nevada

(1) Rentals - Each lease brings in $1/acre per year annual rental (minimum) which increases on a graduated basis after the fifth year. Advance rentals filed during the first three months of filing in Nevada total 1.7 million dollars.

(2) Royalties - When production is reached, royalties of 10-15% of the value of the steam are assessed. Royalties up to 5% are also paid on by-product minerals, including commercial demineralized water.

At the Geysers, a royalty of 10% of the steam value is paid to private landowners. The royalty averages about $250,000 per year per 100 MW plant. With 400 MW capacity, the royalty is about 1 million dollars per year from a production area about two miles wide by seven miles long.

(3) Bonus Bids - On competitive lease sales, bonus bids are an additional source of revenue. In the first federal lease sale held in California on January 22, 1974, twenty leasing units were bid on with 57 bids totalling $12-1/2 million. The highest bid for a single leasing unit was $3,200,000, which amounts to $1,367.50 per acre for the 2,340 acre unit.

(B) Indirect Revenues

Taxation by State and local subdivisions accounts for an additional increment of revenue. Taxes paid to Sonoma Co. from the Geysers approximate $1 million per year for the current 400 MW capacity.

Dr. Robert W. Rex, President of Republic Geothermal Inc., in remarks to the Sub-Committee on Energy, Committee on Science and Astronautics, U. S. House of Representatives, on September 18, 1973, said in part "...Every 1000 megawatts of goethermal development on Federal lands yield about $1 billion of public revenue; 73% to the Federal government, 11% to State governments which have income taxes...and 18% to County governments.

(C) Direct Expenditures

Development of a 110 MW plant costs $15-17.5 million at the Geysers. Individual wells cost about $150,000-$200,000 each.

(D) Indirect Expenditures

The local business community will be affected by geothermal development, both by increased business and by having to provide additional services.

During exploration drilling, two drilling rigs might be used for 1-2 years. Employees would consist of about 40 people directly involved in drilling, with 10-20 additional service people intermittently involved.

Development would advance in 55-110 MW increments in an orderly fashion over a period of 2-10 years. Drill crews for 2-3 rigs would number 40-60, and 20-30 additional people would be involved in plant construction. All of the above personnel would be temporary.

Once the field is operating on stream, about five (5) permanent employees are needed for field production plus five (5) more for each 110 MW plant. One drilling rig would be needed full time, adding 20 more permanent employees to the area.

Thus, for several years, a local community would be burdened with providing necessary school and service facilities for between 40 and 90 additional temporary families. Thereafter, 30 or more families would become permanent residents, also requiring services.

In the short run, communities near a geothermal development would be financially strained. However, such development is capital intensive and in a few years the increased tax base should be much greater than community expenditure on a per capita basis of additional residents.

Other Considerations

This technical report is addressed principally to electrical power generation from vapor dominated and hot water geothermal systems. There are other uses and other geothermal systems that might be involved.

(A) Uses - The heat from geothermal fields may be used for space heating, greenhouse heating, vegetable dehydration and a myraid of other uses for which a heat source is required. Water also might be used for a variety of purposes. The impacts of these uses would be less than the impacts of power generation.

(B) Systems - The hot water and steam systems offer the best chance of commercial use in the near future. For long range consideration two other systems may, with developing technology, become useful.

(1) Hot Dry Rock Systems - Basically similar in origin to the water or steam systems, but lack water to form a convection cell. Such areas may be susceptible to fracturing and introduction of water to develop steam for power generation. Exploration of what is believed to be a hot dry rock geothermal area is currently being carried out on national resource lands near Marysville, Montana by Battelle Northwest Institute under a National Science Foundation grant.

(2) Geopressurized Reservoir Systems - Consist of hot brines under great pressure in marine sediments along the Gulf Coast. They are thought to represent an accumulation of heat due to the normal heat flow being trapped by an insulating layer of under-compacted clay. The resource is large, but years will be required to develop the technology for commercial use.

Stipulations

To be effective, stipulations must be feasible, understandable, germane (related to a specific problem), not redundant, and enforceable.

(A) General Stipulations - The regulations and the standard lease form contain stipulations that cover most general environmental problems. They require among other things, that the lessee shall comply with all Federal and State pollution standards (air, land, water and noise) and that the lessee shall take all mitigating actions required by the lessor to protect the environment and to restore any lands affected by the operation.

(B) Special Lease Stipulations - Care must be taken to avoid using special stipulations that reiterate general stipulations already covered. Special stipulations should relate to specific lease conditions that will have a significant operational or economic impact on the lessee. Generally, these will involve:

(1) Restrictions on surface occupancy.

(2) Restrictions on time of year when operations will be permitted.

More detailed stipulations can best be developed during the operational stage.

(C) Plan of Operation Stipulations - Detailed stipulations such as erosion control, road and drill site locations and standards, surface facilities, restoration requirements, etc. are developed when the plan of operation is being reviewed. The plan provides the detailed information on operations, location and methods that allows the development of specific, enforceable stipulations tailored to that plan.

(D) Technical Problems With Stipulations - Some stipulations that would appear to provide improved surface protection may face economic or technical restrictions that are not initially apparent.

For example, directional drilling would lessen surface damage. However, it can add from $20,000 to $100,000 extra cost per hole (depending on the angle). Also, directional work in hot holes presents special problems in getting surveys to accurately locate the bottom of the hole as most survey systems involve photographic film which is severely affected by the heat.

In addition, directional drilling may pose a significantly greater safety hazard. The extreme temperature differences from drilling to producing conditions (often 400oF or more) may create unsafe stresses on casing. Stuck drill pipe is much more common in directional drilling. In hot holes, the greatest danger of blowouts occurs when mud temperatures exceed the boiling point-depth curve. Any excess down time without circulation, such as a stuck drill pipe, greatly increases the chances of a serious blowout due to the mud boiling off and blowing out of the hole.

Developing stipulations with technologic or economic implications must be closely coordinated with the Geological Survey to assure that such stipulations are sound.

Acknowledgements

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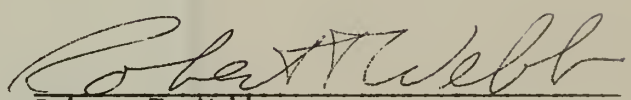

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